OCEAN DATA ASSIMILATION WITH A MODIFIED INTERMITTENT DYNAMIC RELAXATION

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The intermittent approach to data assimilation basing on repeating prediction-analysis cycles is one of the most commonly used in meteorological and oceanographic applications. In this approach, a three-dimensional analysis is being implemented using as input the vector of all observational data $\mathbf{y}^o(t_i)$ attributable to times t_i within the analysis window $t_0 \le t_i \le t_0 + \Delta T$, where ΔT is the window width. The vector of increments $\delta \mathbf{w}^a$ obtained from this analysis is added to the first guess $\mathbf{w}^b(t_a)$ so as to obtain the analysis $\mathbf{w}^a(t_a) = \mathbf{w}^b(t_a) + \delta\mathbf{w}^a$ attributable to time t_a within the same window $t_0 \le t_a \le t_0 + \Delta T$. The analysis $\mathbf{w}^a(t_a)$ is then used as an estimate of the model initial state for calculating the first guess in the next assimilation cycle $\mathbf{w}^b(t_a + \Delta T)$.

The most serious shortcoming of such scheme is the introduction of discontinuity to the time derivatives of the state variables $\mathbf{w}$ at the time moments t_a, $t_a + \Delta T$, $t_a + 2\Delta T$, ... Abrupt change of $\mathbf{w}$ during its replacement by the analysis $\mathbf{w}^a = \mathbf{w}^b + \delta\mathbf{w}^a$ may lead to the development of unphysical disturbances due to the imbalance between different variables.

This shortcoming has been corrected in the becoming widely spread version of the intermittent scheme referred to as Incremental Analysis Updates (IAU) (Bloom et al., 1996). In IAU, the single-stage introduction of the total increment $\delta\mathbf{w}^a$ is replaced by gradual adding portions of this increment $\delta\mathbf{w}^a \Delta t / \Delta T$ during model propagation at each model time step $k = 1,2,...,K$ in a time range $t_a \le t_k \le t_a + \Delta T$:

$$\mathbf{w}_k = M_k(\mathbf{w}_{k-1}) + \delta\mathbf{w}^a \Delta t / \Delta T. \tag{1}$$

where Δt is the model time step, K is the number of model time steps in the assimilation window, and M_k is the forecast model operator that propagates the state from time t_{k-1} to time t_k.

The last term in (1) represents an additional forcing acting at each model time step and independent on the current model state $\mathbf{w}_k$.

Introducing the additional forcing to the model propagation operator is used in one more assimilation scheme referred to as dynamic relaxation (DR) or nudging:

$$\mathbf{w}_k = M_k(\mathbf{w}_{k-1}) - r\Delta t(\mathbf{w}_k - \mathbf{w}^a), \tag{2}$$

where r is the relaxation coefficient, and $\mathbf{w}^a = \mathbf{w}^a(t_a + \Delta T) = \mathbf{w}^b(t_a + \Delta T) + \delta\mathbf{w}^a$ is the analysis attributable to the end of assimilation window.

In contrast to (1) the additional forcing in DR depends on the current model state $\mathbf{w}_k$. Filtering properties of both schemes in their linear approximations are considered in (Bloom et al., 1996).

Both these schemes have an attractive property to suppress the undesired jumps in time of the state variables $\mathbf{w}$ during the assimilation process. Neither of these schemes, however, provides the match of the state variables $\mathbf{w}$ calculated according to (1) or (2) with the analysis $\mathbf{w}^a(t_a + \Delta T) = \mathbf{w}^b(t_a + \Delta T) + \delta\mathbf{w}^a$ at the end of the assimilation window, $t = t_a + \Delta T$. The implications of this mismatch may most clearly manifest themselves for the variables with strictly limited range of variability, such as, for example, the sea ice concentration, which by definition must be within the range (0, 1), or the sea water salinity, which must be nonnegative. Due to the nonlinearity of the model operator M_k the state variables computed by (1) may go beyond the physically permissible limits.

The mismatch can be avoided in the following modification of the intermittent scheme similar to IAU and DR:

$$\mathbf{w}_k = M_k(\mathbf{w}_{k-1}) - (\Delta T - k\Delta t)^{-1} \Delta t(\mathbf{w}_k - \mathbf{w}^a), \tag{3}$$

This scheme, which will be referred to as Modified Dynamical Relaxation (MDR), differs from the conventional relaxation (2) in that the relaxation coefficient $(\Delta T - k\Delta t)^{-1}$ is no longer constant, but increases to the end of the assimilation window ensuring the tendency $\mathbf{w} \to \mathbf{w}^a$ at $t \to t_a + \Delta T$.

A preliminary examination of scheme (3) in its comparison with scheme (1) has been performed in numerical experiments with an ocean general circulation model NEMO (Madec, 2008) coupled with a thermodynamic sea ice model LIM-2 (Fichefet et al., 1997). Used in the experiments, the ORCA1 configuration of the model had a global computational domain covered by a curvilinear tripolar grid at a base horizontal resolution of about 100 km in the main body of the domain and increasing in the near equatorial and near polar regions. The atmospheric forcing was specified using the COARE bulk algorithm with input data from the Global Forecast System (GFS) NCEP/NOAA (Environmental Modeling Center, 2003). The net heat flux at the ocean surface included the relaxation correction ~ $(\theta - \theta_s)$, where θ is the current value of water temperature in the upper model layer, and θ_s is the sea surface temperature according to GFS.

Analysis of observational data was performed with a three-dimensional variational 3DVar scheme (Tsyrulnikov et al., 2006) using as input the measurements of temperature and salinity in the upper 1500 m water layer from Argo profiling floats. The entire period of assimilation 1.01.2011-17.12.2011 included 36 cycles, each of which had a duration of 10 days.

The observational innovations being input to the 3D Var analysis were determined as deviations of observations from the first guess fields computed by the model and varied from day to day according to the FGAT methodology.

The results of these experiments are illustrated in Figure 1, which shows the vertical distributions of mean temperature and salinity deviations (biases) of measurements from the analysis averaged throughout the computational domain and through all 36 assimilation cycles. In calculating these deviations, only the independent data were used (one out of ten daily portions of data, which were excluded from the input data stream for the 3D Var analysis). Excluded from the calculation were also the measurements at a distance of less than 100 km from the nearest land.

As can be seen from Figure 1, the biases in MDR are somewhat smaller than in IAU for temperature and roughly the same for salinity. The differences of root-mean-square deviations between the two schemes were insignificant. Thus, the proposed MDR scheme has at least not worse properties in comparison with IAU. But for more substantiated conclusions, further experiments are needed over longer assimilation periods and with a more detailed tuning of the model and assimilation parameters.

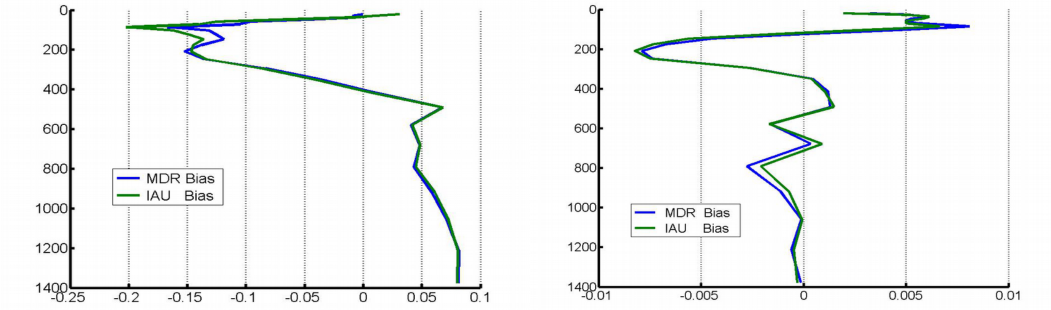

Figure 1. Vertical distributions of mean temperature (°C, left panel) and salinity (psu, right panel) deviations (biases) of independent measurements from the analysis averaged throughout the computational domain and through all 36 assimilation cycles obtained with IAU (green curves) and MDR (blue curves) schemes.

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